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Stallmann

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(54) **METHOD OF CLEANING A CARBON DIOXIDE CONTAINING GAS, AND A CARBON DIOXIDE PURIFICATION SYSTEM**

(71) Applicant: **ALSTOM Technology Ltd**, Baden (CH)

(72) Inventor: **Olaf Stallmann**, Essenheim (DE)

(73) Assignee: **ALSTOM Technology Ltd**, Baden (CH)

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See application file for complete search history.

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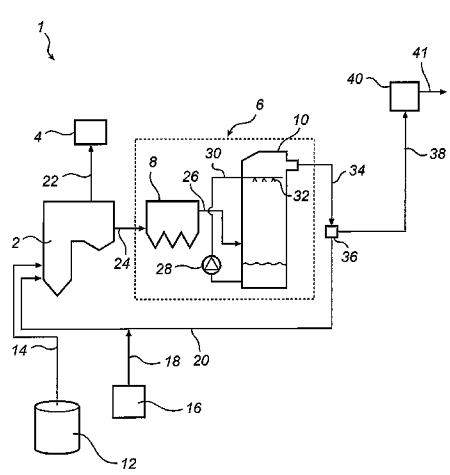
(57) **ABSTRACT**

A gas purification system for cleaning a carbon dioxide rich flue gas generated in a boiler combusting a fuel in the presence of a gas containing oxygen. The gas purification system includes a compressor for compressing the carbon dioxide rich flue gas, a first gas cooler for cooling the compressed carbon dioxide rich flue gas, a mercury adsorber arranged downstream of the first gas cooler for removing at least a portion of a mercury content of the cooled compressed carbon dioxide rich flue gas, a second gas cooler arranged downstream of the mercury adsorber for further cooling the compressed carbon dioxide rich flue gas, and a gas drier for removing at least a portion of a water content of the further cooled compressed carbon dioxide rich flue gas.

12 Claims, 4 Drawing Sheets



(51) **Int. Cl.**

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F23J 15/00	(2006.01)
F23J 15/06	(2006.01)
F25J 3/06	(2006.01)
F25J 3/02	(2006.01)

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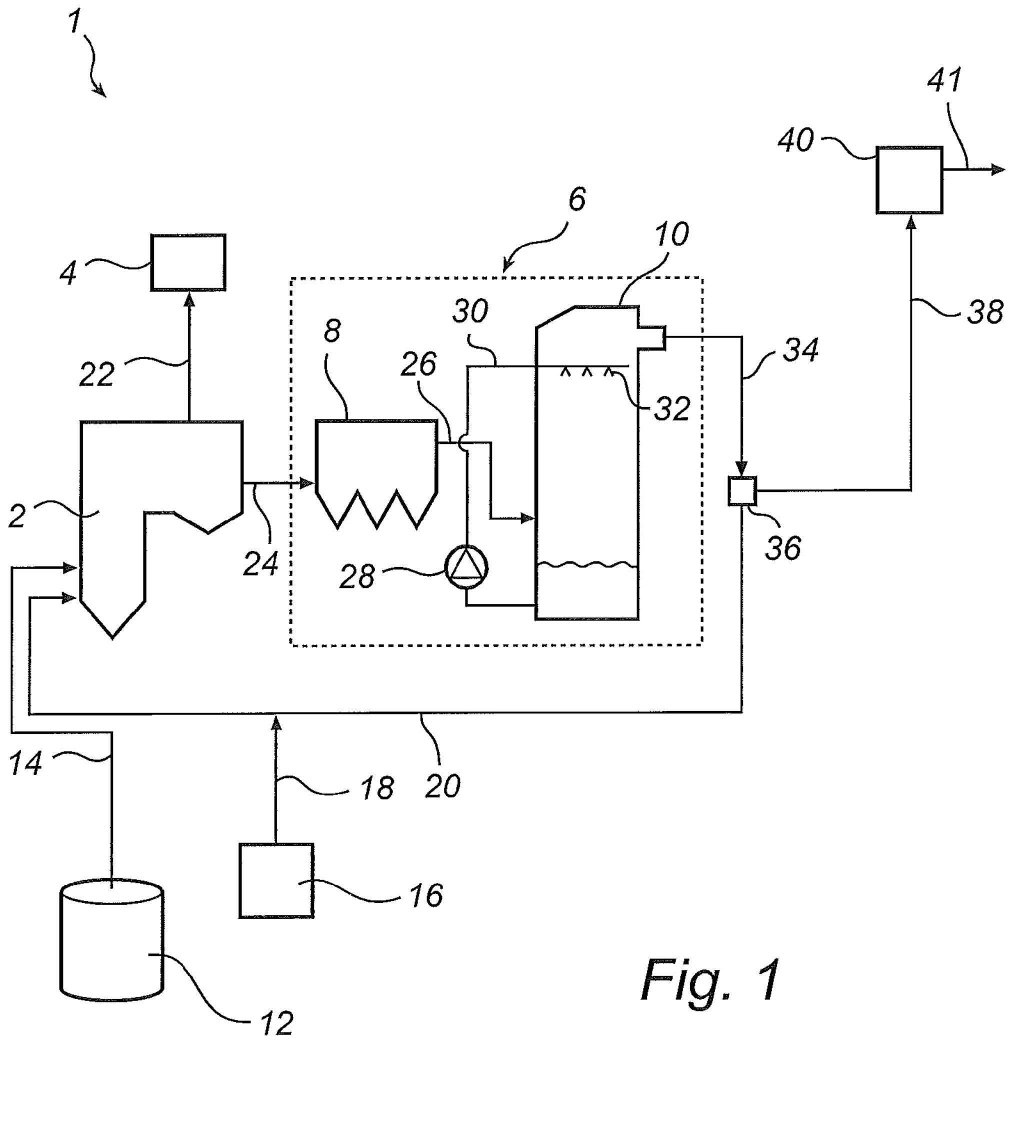

Fig. 1

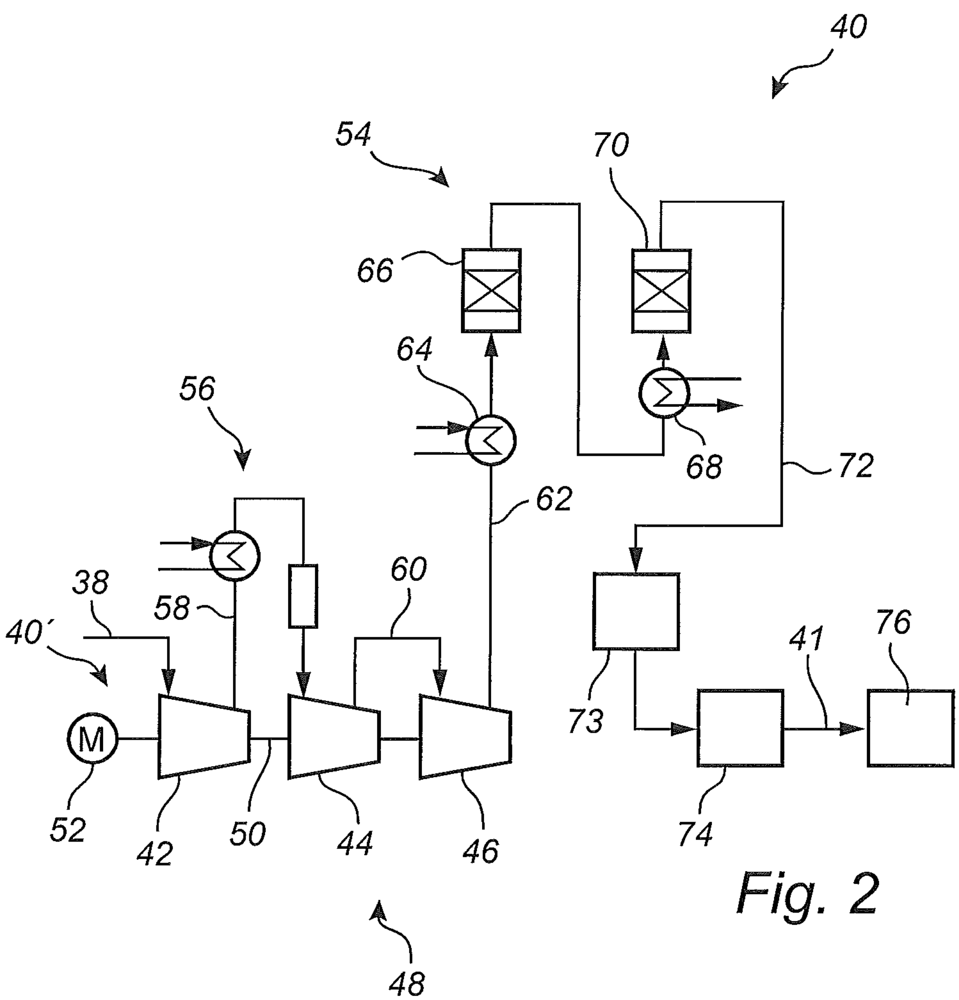

Fig. 2

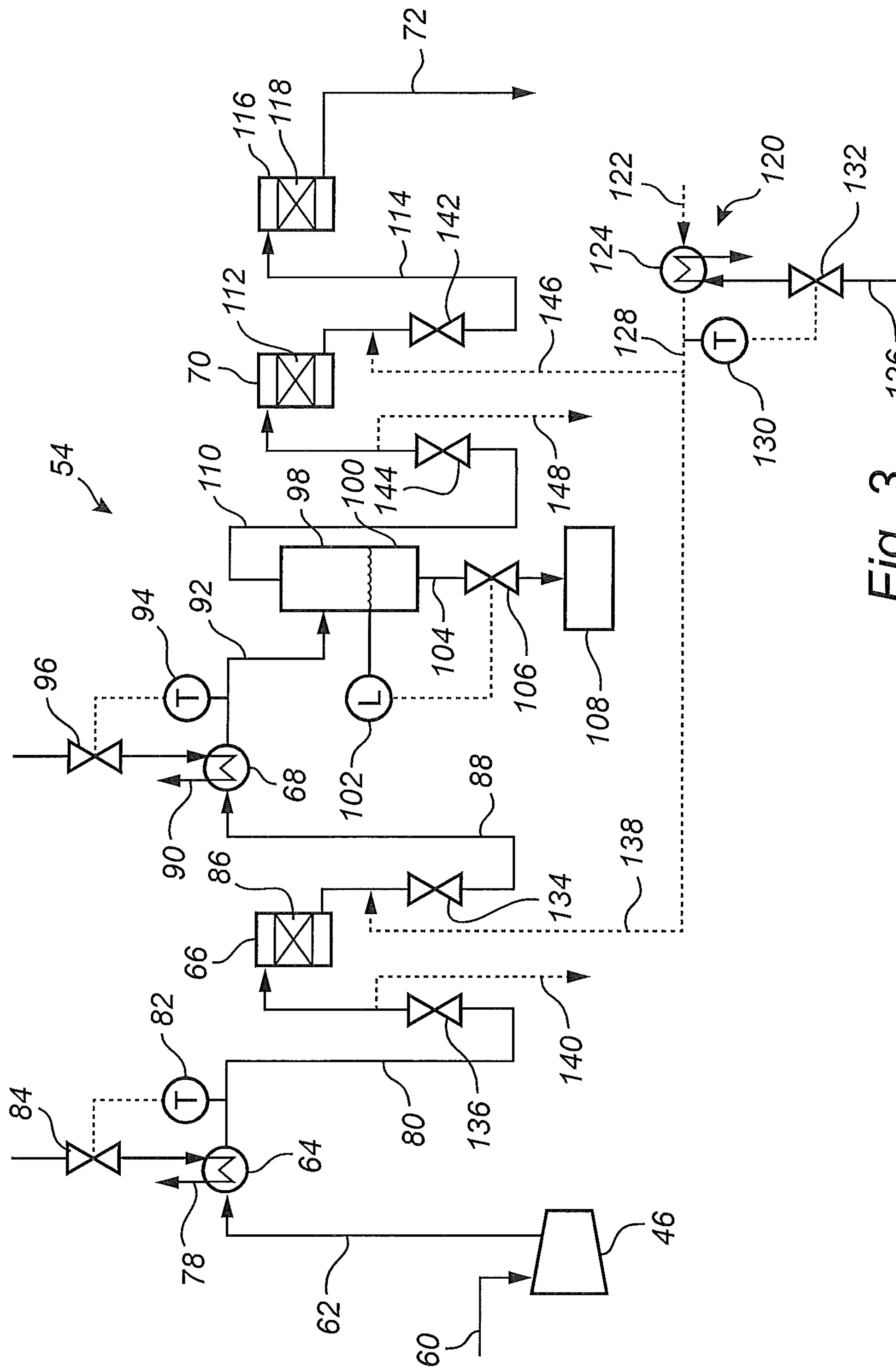
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Fig. 3

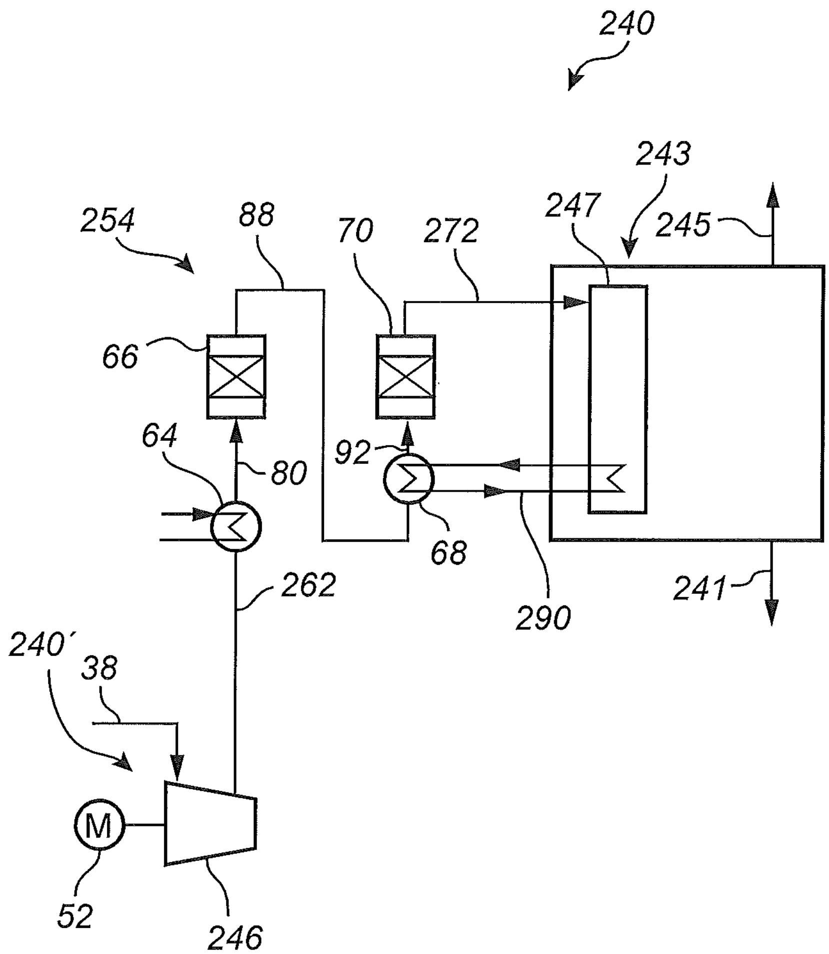
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Fig. 4

METHOD OF CLEANING A CARBON DIOXIDE CONTAINING GAS, AND A CARBON DIOXIDE PURIFICATION SYSTEM

CROSS-REFERENCES TO RELATED APPLICATIONS

This application claims priority to PCT/IB2012/000037 filed Jan. 13, 2012, which claims priority to European Application 11150940.2 filed Jan. 14, 2011, both of which are hereby incorporated in their entireties.

TECHNICAL FIELD

The present invention relates to a method of cleaning a carbon dioxide rich gas generated in a boiler combusting a fuel in the presence of a gas containing oxygen gas.

The present invention further relates to a gas purification system for cleaning a carbon dioxide rich gas generated in a boiler system comprising a boiler for combusting a fuel in the presence of a gas containing oxygen gas.

BACKGROUND

In the combustion of a fuel, such as coal, oil, peat, waste, etc., in a combustion plant, such as a power plant, a hot process gas is generated, such process gas containing, among other components, carbon dioxide CO_2. With increasing environmental demands various processes for removing carbon dioxide from the process gas have been developed. One such process is the so called oxy-fuel process. In an oxy-fuel process a fuel, such as one of the fuels mentioned above, is combusted in the presence of a nitrogen-lean gas. Oxygen gas, which is provided by an oxygen source, is supplied to a boiler in which the oxygen gas oxidizes the fuel. In the oxy-fuel combustion process a carbon dioxide rich flue gas is produced, which can be disposed of in order to reduce the emission of carbon dioxide into the atmosphere.

Prior to being disposed of, it is necessary to clean the carbon dioxide gas. WO 2010/021053 discloses a gas cleaning system in which a hot process gas generated in a boiler is subjected to removal of nitrogen oxides, dust, and sulphur dioxide. The hot process gas, being a carbon dioxide rich gas, is then subjected to a mercury removal step to clean the carbon dioxide rich gas prior to the disposal thereof.

SUMMARY

An object of the present invention is to provide a method of cleaning a carbon dioxide rich flue gas generated in a boiler combusting a fuel in the presence of a gas containing oxygen gas, the method being more efficient than the prior art method.

This object is achieved by means of a method of cleaning a carbon dioxide rich flue gas generated in a boiler combusting a fuel in the presence of a gas containing oxygen gas, the method comprising

compressing the carbon dioxide rich flue gas,

cooling the compressed carbon dioxide rich flue gas to a first temperature,

forwarding the cooled compressed carbon dioxide rich flue gas through a mercury adsorber to remove at least a portion of a mercury content of the cooled compressed carbon dioxide rich flue gas,

further cooling the compressed carbon dioxide rich flue gas to a second temperature, which is lower than the first temperature, and

forwarding the further cooled compressed carbon dioxide rich flue gas through a drier to remove at least a portion of a water content of the further cooled compressed carbon dioxide rich flue gas.

An advantage of this method is that both the mercury adsorption and the removal of water vapour may be achieved at effective temperatures for the respective operation. Furthermore, there is no need for heating the gas between the two operations, thus reducing the power consumption.

According to one embodiment the step of cooling the compressed carbon dioxide rich flue gas to a first temperature comprises cooling to a first temperature being higher than the dew point temperature with respect to water vapour of the compressed carbon dioxide rich flue gas. An advantage of this embodiment is that condensation of water vapour in the mercury adsorber is avoided. Such condensation could be detrimental to the efficiency and life of the mercury adsorber and the active materials used therein.

According to one embodiment the step of cooling the gas to a first temperature comprises cooling the gas to a first temperature being 5 to 30° C. higher than the dew point temperature with respect to water vapour of the compressed carbon dioxide rich flue gas. Cooling to a temperature of less than 5° C. above the dew point temperature is less attractive, since the risk of water vapour condensation increases. Cooling to a temperature of more than 30° C. above the dew point temperature is also less attractive, since the efficiency of mercury adsorption decreases.

According to one embodiment the step of further cooling the compressed carbon dioxide rich flue gas to a second temperature, which is lower than the first temperature, comprises cooling to a second temperature being lower than the dew point temperature with respect to water vapour of the compressed carbon dioxide rich flue gas. An advantage of this embodiment is that some condensation of water vapour occurs, which increases the efficiency of the downstream drier.

According to one embodiment the step of further cooling the compressed carbon dioxide rich flue gas comprises cooling to a second temperature being 0 to 40° C. higher than the carbon dioxide hydrate formation temperature of the compressed carbon dioxide rich flue gas. Cooling to a temperature which is lower than the carbon dioxide hydrate formation temperature is less attractive, since formation of solid carbon dioxide hydrate may be detrimental to the operation of a cooler in which the step of further cooling the compressed carbon dioxide rich flue gas is performed. Cooling to a temperature of more than 40° C. above the carbon dioxide hydrate formation temperature is also less attractive, since the efficiency of water vapour adsorption in the gas drier becomes less efficient, resulting in a need for an unnecessarily large and expensive drier.

According to one embodiment the step of compressing the carbon dioxide rich flue gas involves heating, by means of the compression of the gas, the compressed carbon dioxide rich flue gas to a temperature which is higher than the first temperature. An advantage of this embodiment is that the heat of compression is utilized for obtaining a starting temperature, from which the gas can be cooled to the first and second temperatures. Hence, no additional heating is needed during normal operation.

According to one embodiment, the compression of the carbon dioxide rich flue gas involves heating, by means of the compression of the gas, the compressed carbon dioxide rich flue gas to a temperature of 60 to 270° C. An advantage of this embodiment is that a temperature of 60 to 270° C. is often attainable as a result of compression by a compressor working efficiently to compress the carbon dioxide rich flue gas. A temperature of less than 60° C. after compression often means that the compression has resulted in a rather low pressure of the compressed gas. Hence, more compression stages would be needed. A temperature of more than 270° C. after compression often means that compression has been less energy efficient, resulting in excessive heat losses.

A further object of the present invention is to provide a purification system for cleaning a carbon dioxide rich flue gas generated in a boiler combusting a fuel in the presence of a gas containing oxygen gas, the purification system being more efficient than the prior art systems.

This object is achieved by means of a gas purification system for cleaning a carbon dioxide rich flue gas generated in a boiler combusting a fuel in the presence of a gas containing oxygen gas, the gas purification system comprising:

a compressor for compressing the carbon dioxide rich flue gas,

a first gas cooler arranged downstream, as seen in the direction flow of the carbon dioxide rich flue gas, of the compressor for cooling the compressed carbon dioxide rich flue gas,

a mercury adsorber arranged downstream of the first gas cooler for removing at least a portion of a mercury content of the cooled compressed carbon dioxide rich flue gas,

a second gas cooler arranged downstream of the mercury adsorber for further cooling the compressed carbon dioxide rich flue gas, and

a gas drier arranged downstream of the second gas cooler for removing at least a portion of a water content of the further cooled compressed carbon dioxide rich flue gas.

An advantage of this purification system is that it is very efficient with regard to investment and operating costs. It is not necessary to include a separate heater, and heating power requirements are limited.

According to one embodiment the purification system further comprises a control system comprising a sensor measuring the temperature of the cooled compressed carbon dioxide rich flue gas downstream of the first gas cooler, the control system further comprising a control device controlling the first gas cooler in view of the measured temperature. An advantage of this embodiment is that it becomes possible to control very accurately the operating temperature of the mercury adsorber.

According to one embodiment the purification system comprises a water trap arranged between the second gas cooler and the gas drier for collecting liquid water from the further cooled compressed carbon dioxide rich flue gas. An advantage of this embodiment is that the water load on the gas drier can be reduced. Hence, the gas drier size can be minimized, still providing the same residual water content in the carbon dioxide rich flue gas leaving the gas drier.

According to one embodiment the gas purification system comprises a heating system for forwarding a heated gas through the mercury adsorber prior to start-up of the gas purification system. An advantage of this embodiment is that the risk of condensation of water vapour inside the mercury adsorber during start-up is reduced.

Further objects and features of the present invention will be apparent from the description and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described in more detail with reference to the appended drawings in which:

FIG. **1** is a schematic side view of a boiler system.

FIG. **2** is a schematic side view of a gas compression and purification unit.

FIG. **3** is schematic side view of an inter-cooling and mercury adsorption unit.

FIG. **4** is a schematic side view of a cryogenic carbon dioxide separation process.

DETAILED DESCRIPTION

FIG. **1** is a schematic representation of a boiler system **1**, as seen from the side thereof. The boiler system **1** comprises, as main components, a boiler **2**, being in this embodiment an oxy-fuel boiler, a steam turbine electric power generation system, schematically indicated as **4**, and a gas cleaning system **6**. The gas cleaning system **6** comprises a particulate removal device, which may, for example, be a fabric filter or an electrostatic precipitator **8**, and a sulphur dioxide removal system, which may be a wet scrubber **10**.

A fuel, such as coal, oil, or peat, is contained in a fuel storage **12**, and can be supplied to the boiler **2** via a supply pipe **14**. An oxygen gas source **16** is operative for providing oxygen gas in a manner which is known per se. The oxygen gas source **16** may be an air separation plant operative for separating oxygen gas from air, an oxygen separating membrane, a storage tank, or any other source for providing oxygen gas to the boiler system **1**. A supply duct **18** is operative for forwarding the produced oxygen gas, comprising typically 90-99.9 vol. % oxygen, O_2, to the boiler **2**. A duct **20** is operative for forwarding recirculated flue gas, which contains carbon dioxide, to the boiler **2**. As indicated in FIG. **1**, the supply duct **18** joins the duct **20** upstream of the boiler **2**, such that oxygen gas and recirculated flue gas, which contains carbon dioxide, may become mixed with each other to form a gas mixture containing typically about 20-50% by volume of oxygen gas, the balance being mainly carbon dioxide and water vapour, upstream of the boiler **2**. Since almost no air enters the boiler **2** there is almost no nitrogen gas supplied to the boiler **2**. In practical operation, less than 3% by volume of the gas volume supplied to the boiler **2** is air, which mainly enters the boiler system **1** as a leakage of air via, for example, the boiler **2** and the gas cleaning system **6**. The boiler **2** is operative for combusting the fuel, that is to be supplied via the supply pipe **14**, in the presence of the oxygen gas, mixed with the recirculated flue gas, which contains carbon dioxide, that is to be supplied via the duct **20**. A steam pipe **22** is operative for forwarding steam, that will be produced in the boiler **2** as a result of the combustion, to the steam turbine electric power generation system **4**, which is operative for generating power in the form of electric power.

A duct **24** is operative for forwarding carbon dioxide rich flue gas generated in the boiler **2** to the dust removal device **8**. By "carbon dioxide rich flue gas" is meant that the flue gas leaving the boiler **2** via the duct **24** will contain at least 40% by volume of carbon dioxide, CO_2. Often more than 50% by volume of the flue gas leaving the boiler **2** will be carbon dioxide. Typically, the flue gas leaving boiler **2** will contain 50-80% by volume of carbon dioxide. The balance of the "carbon dioxide rich flue gas" will be about 15-40% by volume of water vapour (H_2O), 2-7% by volume of oxygen (O_2), since a slight oxygen excess is often preferred in the boiler **2**, and totally about 0-10% by volume of other gases, including mainly nitrogen (N_2) and argon (Ar), since some leakage of air can seldom be completely avoided.

The carbon dioxide rich flue gas generated in the boiler **2** may typically comprise contaminants in the form of, for example, dust particles, hydrochloric acid, HCl, sulphur oxides, SO_x, and heavy metals, including mercury, Hg, that should be removed, at least partly, from the carbon dioxide rich flue gas prior to disposing of the carbon dioxide.

The dust removal device **8** removes most of the dust particles from the carbon dioxide rich flue gas. A duct **26** is operative for forwarding the carbon dioxide rich flue gas from the fabric filter **8** to the wet scrubber **10** of the gas cleaning system **6**. The wet scrubber **10** comprises a circulation pump **28** which is operative for circulating, in a slurry circulation pipe **30**, an absorption liquid, comprising for example lime stone, from the bottom of the wet scrubber **10** to a set of nozzles **32** arranged in the upper portion of the wet scrubber **10**. The slurry nozzles **32** are operative for finely distributing the absorption liquid in the wet scrubber **10** to achieve good contact between the absorption liquid and the flue gas being forwarded to the wet scrubber **10** via the duct **26** and flowing substantially vertically upwards inside the wet scrubber **10** to effect efficient removal of sulphur dioxide, SO_2, and other acid gases from the carbon dioxide rich flue gas.

An at least partly cleaned carbon dioxide rich flue gas leaves the wet scrubber **10** via a duct **34** which forwards the flue gas to a gas splitting point **36**, where the at least partly cleaned carbon dioxide rich flue gas is divided into two flows, namely a first flow, which via the duct **20** is recirculated back to the boiler **2**, and a second flow, which via a duct **38** is forwarded to a gas purification system in the form of a gas compression and purification unit (GPU) **40** of the boiler system **1**. In the GPU **40** the cleaned carbon dioxide rich flue gas is further cleaned and is compressed for disposal. Compressed carbon dioxide hence leaves the GPU **40** via a duct **41** and is transported away for disposal, which is sometimes referred to as "CO_2 sequestration". The first flow, which is recirculated back to the boiler **2** via duct **20**, typically comprises 50-75% by volume of the total flow of the partly cleaned carbon dioxide rich flue gas leaving the wet scrubber **10**. The second flow, typically comprising 25-50% by volume of the total flow of the partly cleaned carbon dioxide rich flue gas leaving the wet scrubber **10**, is, hence, forwarded, via the duct **38**, to the GPU **40**, which will be described in more detail hereinafter.

FIG. **2** illustrates the GPU **40** in more detail. It will be appreciated that the illustration of FIG. **2** is schematic, and that a GPU may comprise further devices for gas purification etc.

The GPU **40** comprises at least one compressor having at least one, and typically two to ten compression stages for compressing the cleaned carbon dioxide rich flue gas. Each compression stage could be arranged as a separate unit. As alternative, and as illustrated in FIG. **2**, several compression stages could be operated by a common drive. The GPU **40** of FIG. **2** comprises a compressor **40'** having a first compression stage **42**, a second compression stage **44**, and a third compression stage **46**. The first to third compression stages **42**, **44**, **46** form together a low pressure compression unit **48** of the GPU **40**. The compression stages **42**, **44**, **46** are connected to a common drive shaft **50** which is driven by a motor **52** of the compressor **40'**.

The GPU **40** comprises at least one gas purification system inter-cooling and mercury adsorption unit **54** which is arranged downstream of one of the compression stages **42**, **44**, **46**. In the embodiment of FIG. **2**, the inter-cooling and mercury adsorption unit **54** is arranged downstream of the third compression stage **46**, i.e., downstream of the low pressure compression unit **48**. It will be appreciated that the inter-cooling and mercury adsorption unit **54** could also have been arranged downstream of the first compression stage **42**, or downstream of the second compression stage **44**. It is also possible to arrange more than one inter-cooling and mercury adsorption unit **54** in the GPU, for example one inter-cooling and mercury adsorption unit downstream of the second compression stage **44**, and one inter-cooling and mercury adsorption unit **54** downstream of the third compression stage **46**. Still further, it is also possible to arrange an intercooling unit **56**, having the intercooling functionality of the inter-cooling and mercury adsorption unit **54** but lacking the mercury adsorption functionality thereof, downstream of some, or all, of those compression stages that have no inter-cooling and mercury adsorption unit **54** arranged downstream thereof. Hence, intercooling units **56** may be arranged downstream of the first, and second compression stages **42**, and **44** of the GPU **40** of FIG. **2**. One such optional intercooling unit **56** is illustrated downstream of the first compression stage **42**.

The cleaned carbon dioxide rich flue gas enters the GPU **40** via the duct **38** and is introduced into the first compression stage **42**. A duct **58** forwards, optionally via the intercooling unit **56**, the compressed gas from the first compression stage **42** to the second compression stage **44**. A duct **60** forwards, optionally via a not shown intercooling unit, the compressed gas from the second compression stage **44** to the third compression stage **46**. A duct **62** forwards the compressed gas from the third compression stage **46** to the inter-cooling and mercury adsorption unit **54**.

The main parts of the inter-cooling and mercury adsorption unit **54** are a first gas cooler **64**, a mercury adsorber **66**, a second gas cooler **68**, and a gas drier **70**. The mercury adsorber **66** is operative for removing at least a portion of the mercury content of the compressed gas. The gas drier **70** serves to remove at least a portion of the content of water vapour of the compressed gas. The parts of the inter-cooling and mercury adsorption unit **54** will be described in more detail hereinafter with reference to FIG. **3**.

A duct **72** forwards the compressed gas, from which at least a portion of its mercury and water vapour content has been removed, from the inter-cooling and mercury adsorption unit **54** to optional further units of the GPU **40**. Examples of such optional further units of the GPU **40** include a non-condensable gas removal unit, for example a CO_2 liquefaction unit **73**, in which the gas is cooled in a heat-exchanger, often called a cold-box, to cause liquefaction of the carbon dioxide such that the carbon dioxide can be separated from gases, such as nitrogen, that are not liquefied at the same temperature as carbon dioxide. Furthermore, the GPU **40** may comprise a high pressure compression unit **74** arranged downstream, as seen with respect to the transport direction of the carbon dioxide, of the CO_2 liquefaction unit **73**, and comprising one or more compression stages for compressing the carbon dioxide to a suitable pressure for sequestration. After compression of the gas in the high pressure compression unit **74**, the compressed carbon dioxide, which may be in a supercritical or liquid state, is forwarded, via duct **41**, to a CO_2 sequestration site **76**.

FIG. **3** describes the inter-cooling and mercury adsorption unit **54** in more detail. The carbon dioxide rich flue gas compressed in the third compression stage **46** enters the inter-cooling and mercury adsorption unit **54** via the fluidly connected duct **62**. The compressed carbon dioxide rich flue gas may, just downstream of the third compression stage **46**, have a pressure of 10-60 bar absolute pressure, and, typically, a temperature of 60 to 270° C., which is a starting temperature of that gas on which the inter-cooling and mercury adsorption unit **54** is to perform its operations. In one example, the compressed carbon dioxide rich flue gas leaving the third compression stage **46** may have a starting temperature of 120° C. and a pressure of 35 bar absolute pressure.

The compressed carbon dioxide rich flue gas enters, via fluidly connected duct **62**, the first gas cooler **64**. A cooling medium circuit **78** is connected to the first gas cooler **64** for circulating a cooling medium, such as cooling air, cooling water, cooling oil, or another suitable coolant, in the first gas cooler **64**. As a further alternative, the first gas cooler **64** could be air-cooled. The cooled compressed carbon dioxide rich flue gas leaves the first gas cooler **64** via fluidly connected duct **80**. A temperature sensor **82** is arranged in the duct **80** to measure the temperature of the cooled compressed carbon dioxide rich flue gas. A damper or valve **84** is arranged in the cooling liquid circuit **78** for controlling the flow of cooling medium to the first gas cooler **64**. The temperature sensor **82** controls the valve **84** to supply a suitable amount of cooling medium. Typically, the temperature sensor **82** controls the flow of cooling medium to the first gas cooler **64** to obtain a cooled compressed carbon dioxide rich flue gas having a first temperature which is 5 to 30° C. above the dew point temperature with respect to water of the compressed carbon dioxide rich flue gas. The dew point temperature is that temperature of a gas mixture at which water vapour starts to condense into liquid water. Liquid water would be detrimental to the function of the downstream mercury adsorber **66**, and, hence, the cooled compressed carbon dioxide rich flue gas is preferably cooled to a first temperature which is above the dew point temperature. The mercury adsorber **66** tends to operate more efficiently the lower the temperature, and, hence, it is preferable to cool to a first temperature which is no more than 30° C. above the dew point temperature with respect to water of the cooled compressed carbon dioxide rich flue gas. In one example, the cooled compressed carbon dioxide rich flue gas leaving the first gas cooler **64** has a first temperature of 60° C., a temperature which is 10° C. above the dew point temperature with respect to water of 50° C. of the cooled compressed carbon dioxide rich flue gas in question.

The cooled compressed carbon dioxide rich flue gas is forwarded via fluidly connected duct **80** to the mercury adsorber **66**. The mercury adsorber **66** is provided with a packing **86** comprising a mercury adsorbent having affinity for mercury. The adsorbent may, for example, be activated carbon impregnated with sulphur, or another material that is, as such, known for its affinity for mercury. Hence, as the cooled compressed carbon dioxide rich flue gas passes through the packing **86**, at least a portion of the content of mercury of the gas will be adsorbed on the mercury adsorbent of the packing **86**.

The cooled compressed carbon dioxide rich flue gas, from which at least a portion of its mercury content has been removed, is forwarded, via fluidly connected duct **88**, to the second gas cooler **68**. Typically, there would be no compressor or other gas heating device arranged between the mercury adsorber **66** and the second gas cooler **68**. A cooling liquid circuit **90** is connected to the second gas cooler **68** for circulating a cooling medium, such as a glycol-water mixture, an ammonia-water mixture, an organic refrigerant, or another suitable coolant, in the second gas cooler **68**. The coolant of the cooling liquid circuit **90** has a lower temperature than the cooled compressed carbon dioxide rich flue gas. Hence, a further cooling of the cooled compressed carbon dioxide rich flue gas is accomplished in the second gas cooler **68**. The further cooled compressed carbon dioxide rich flue gas leaves the second gas cooler **68** via fluidly connected duct **92**. A temperature sensor **94** is arranged in the duct **92** to measure the temperature of the further cooled compressed carbon dioxide rich flue gas. A valve **96** is arranged in the cooling liquid circuit **90** for controlling the flow of coolant to the second gas cooler **68**. The temperature sensor **94** controls the valve **96** to supply a suitable amount of coolant. Typically, the temperature sensor **94** controls the flow of coolant to the second gas cooler **68** to obtain a further cooled compressed carbon dioxide rich flue gas having a second temperature, which is lower than the above-mentioned first temperature, and which is 0 to 40° C. above the carbon dioxide hydrate formation temperature of the compressed carbon dioxide rich flue gas. The carbon dioxide hydrate formation temperature is that temperature of a gas mixture comprising carbon dioxide and water vapour at which a solid hydrate of carbon dioxide and water starts to form, see for example Tamman, G. & Krige, G. J. (1925): "*Equilibrium pressures of gas hydrates*." Zeit. Anorg. and Algem. Chem., 146, pp. 179-195. Formation of solid carbon dioxide hydrates would be detrimental to the function of the second gas cooler **68**, and, hence, the further cooled compressed carbon dioxide rich flue gas is preferably cooled to a second temperature which is above the carbon dioxide hydrate formation temperature. More preferably, the further cooled compressed carbon dioxide rich flue gas is cooled to a second temperature which is above the carbon dioxide hydrate formation temperature, and which is below the dew point temperature with respect to water of the carbon dioxide rich flue gas. By causing a condensation of some of the water vapour, and preferably removing liquid formed thereby in a gas-liquid separator as described hereinafter, the residual water vapour load that has to be removed by the gas drier **70** is reduced. The residual water vapor load that has to be removed by the gas drier **70** is further reduced the lower the temperature, resulting in smaller drier equipment. Hence, it is preferable to cool to a second temperature which is no more than 40° C. above the carbon dioxide hydrate formation temperature of the further cooled compressed carbon dioxide rich flue gas. In one example, the further cooled compressed carbon dioxide rich flue gas has a second temperature of 15° C., a temperature which is 9° C. above the carbon dioxide hydrate formation temperature of 6° C. of the further cooled compressed carbon dioxide rich flue gas in question.

The further cooled compressed carbon dioxide rich flue gas is forwarded via fluidly connected duct **92** to an optional gas-liquid separator **98**. The gas-liquid separator **98** separates water droplets, generated as an effect of condensation caused by the further cooling of the gas in the second gas cooler **68**, from the remaining gas. The water droplets are collected in a lower portion **100** of the gas-liquid separator **98**. A level meter **102** measures the amount of liquid in the gas-liquid separator **98**. A drain pipe **104** arranged in the lower portion **100** of the gas-liquid separator **98** is provided with a valve **106**. The level meter **102** controls the valve **106**, and orders the valve **106** to open when the level of liquid in the gas-liquid separator **98** is too high. When the valve **106** is opened liquid drains from the gas-liquid separator **98** to a water treatment plant **108** via the drain pipe **104**.

The further cooled compressed carbon dioxide rich flue gas is forwarded further from the gas-liquid separator **98** to the gas drier **70** via a fluidly connected duct **110**. The gas drier **70** is provided with a packing **112** comprising a water vapour adsorbent, also referred to as a desiccant, having affinity for water vapour. The desiccant may, for example, be silica gel, calcium sulphate, calcium chloride, montmorillonite clay, molecular sieves, or another material that is, as such, known for its use as a desiccant. Hence, as the further cooled compressed carbon dioxide rich flue gas passes through the packing **112**, at least a portion of the content of water vapour of the gas will be adsorbed on the desiccant of the packing **112**.

The further cooled compressed carbon dioxide rich flue gas, from which at least a portion of its water vapour content has been removed, is forwarded, via fluidly connected duct

114, to an optional filter **116**. The filter **116** is provided with a filtering insert **118**, which may have the form of fabric bags, metal filter nets, ceramic tubes, and other devices that are per se known for efficient removal of solid particles from a gas. Such particles could, for example, originate from the adsorbent material of the packing **86** of the mercury adsorber **66**, and/or from the desiccant of the packing **112** of the gas drier **70**. Particulate material may cause wear to compression stages or blocking of the CO_2 liquefaction unit, and, hence, it may be suitable to remove any particulate material from the gas by means of the filter **116** before forwarding the gas to the CO_2 liquefaction unit **73** and the high pressure compression unit **74**, illustrated in FIG. **2**, via the fluidly connected duct **72**.

In one example, the further cooled compressed carbon dioxide rich flue gas leaving the inter-cooling and mercury adsorption unit **54** via the duct **72** has a temperature of 15° C., and an absolute pressure of just below 30 bar absolute pressure, since a slight pressure drop is normal as the gas passes through the unit **54**. The gas also has a reduced content of mercury and water vapour. Such a gas is suitable for further treatment in the CO_2 liquefaction unit **73** and the high pressure compression unit **74**, and for eventually being sent to carbon dioxide sequestration **76** via duct **41**, as illustrated in FIG. **2**. For example, a heat exchanger, also called a cold box, of the CO_2 liquefaction unit **73** may often be made from aluminium. Aluminium may react with mercury in an unwanted manner. By removing mercury from the carbon dioxide rich flue gas in the adsorber **66**, upstream of the CO_2 liquefaction unit **73**, such problems are avoided, or at least minimized. Furthermore, in some cases it is also necessary to remove mercury from the carbon dioxide to meet the specification required for the CO_2 sequestration **76**.

Returning to FIG. **3**, the inter-cooling and mercury adsorption unit **54** is provided with a regeneration and heating system **120** for intermittent regeneration of the water vapour adsorption capacity of the gas drier **70**. The regeneration and heating system **120** is also utilized for pre-heating of the mercury adsorber **66** at start-up. A supply duct **122** is arranged for supplying a regeneration gas to the system **120**. The regeneration gas is preferably an inert gas which does not react with the packings **86** and **112**. Examples of suitable gases include nitrogen, clean carbon dioxide, coming for example from the duct **41**, or another inert gas that, preferably, holds a low amount of mercury and water vapour. Preferably, inert off gas, usually comprising nitrogen as one of its main constituents, separated from the carbon dioxide in the CO_2 liquefaction unit **73** is utilized as regeneration gas. The regeneration system **120** comprises a heater **124** which is adapted for heating the regeneration gas. A heating circuit **126** is connected to the heater **124** for circulating a heating medium, such as steam, in the heater **124**. The heated regeneration gas leaves the heater **124** via fluidly connected duct **128**. A temperature sensor **130** is arranged in the duct **128** to measure the temperature of the heated regeneration gas. A valve **132** is arranged in the heating circuit **126** for controlling the flow of heating medium to the heater **124**. The temperature sensor **130** controls the valve **132** to supply a suitable amount of heating medium. For pre-heating of the material of the packing **86** of the mercury adsorber **66** at start-up, the heater **124** may typically heat the regeneration gas to a temperature of about 40-80° C. For regeneration of the material of the packing **112** of the gas drier **70**, the heater **124** may typically heat the regeneration gas to a temperature of about 120-300° C.

Mercury adsorber isolation valves **134**, **136** are arranged on the ducts **88**, **80**, respectively. During a pre-heating sequence, the valves **134**, **136** are shut to isolate the mercury adsorber **66**, and heated regeneration gas is supplied to the mercury adsorber **66** from the regeneration and heating system **120** via a duct **138** which is fluidly connected to the duct **128**. The regeneration gas heats the material of the packing **86**. The mercury is firmly bound to the material of the packing **86**, which means that no, or almost no, mercury is released from the packing **86** during the pre-heating thereof. Spent regeneration gas leaves the mercury adsorber **66** via a duct **140**. The spent regeneration gas, containing no, or a very low concentration of mercury, may be released to the atmosphere.

When the packing **86** has adsorbed mercury in accordance with its adsorption capacity, the valves **134**, **136** are closed and the spent packing **86** is replaced with fresh packing **86**.

Gas drier isolation valves **142**, **144** are arranged on the ducts **114**, **110** respectively. During a regeneration sequence, the valves **142**, **144** are shut to isolate the gas drier **70**, and heated regeneration gas is supplied to the gas drier **70** from the regeneration and heating system **120** via a duct **146** which is fluidly connected to the duct **128**. The regeneration gas heats the material of the packing **112** and causes a desorption of water vapour. Spent regeneration gas, containing desorbed water vapour, leaves the gas drier **70** via a duct **148**. Since the mercury adsorber **66** is installed upstream of the gas drier **70**, no mercury, or just a very small amount of mercury, is adsorbed in the material of the packing **112** of the gas drier **70**. Thus, no, or almost no, mercury is desorbed during the regeneration of the gas drier **70**. The spent regeneration gas coming from the gas drier **70** is very clean with respect to mercury and may, thus, be released to the atmosphere.

It will be appreciated that when the valves **134**, **136** are closed, no carbon dioxide rich gas may pass through the mercury adsorber **66**. According to one embodiment, the GPU **40** may be provided with two parallel mercury adsorbers **66**, with one of those parallel adsorbers **66** being in operation while the other parallel adsorber undergoes replacement of the packing **86**. According to another embodiment, the carbon dioxide rich flue gas could be emitted to the atmosphere during the replacement of the packing **86**.

It will also be appreciated that when the valves **142**, **144** are closed, no carbon dioxide rich gas may pass through the gas drier **70**. According to one embodiment, the GPU **40** may be provided with two parallel gas driers **70**, with one of those parallel gas driers **70** being in operation while the other parallel gas drier **70** undergoes regeneration. According to another embodiment, the carbon dioxide rich flue gas could be emitted to the atmosphere during the regeneration of the packing **112** of the gas drier **70**.

At start-up of a boiler system **1**, illustrated in FIG. **1**, most parts of the boiler system **1**, including most parts of the inter-cooling and mercury adsorption unit **54** are cold, which means that they typically have a temperature of around 0-25° C., depending on the ambient temperature. Such low temperatures pose a risk of the temperature of the gas inside the mercury adsorber **66** getting lower, during the start-up phase, than the dew point temperature with respect to water, which could result in unwanted liquid water condensation inside the packing **86**. To avoid such water condensation, the regeneration and heating system **120** is utilized, as mentioned hereinabove, for pre-heating the mercury adsorber **66** prior to the start-up of the GPU **40** being initialized. This pre-heating could be achieved by utilizing the regeneration and heating system **120** for forwarding a heated gas, such as heated nitrogen gas, a heated cleaned carbon dioxide gas, or a heated off gas, for example an off gas containing non-condensable gases such as nitrogen and oxygen, of a temperature of, for example, 40-80° C., to the mercury adsorber **66** via ducts **128** and **138** to achieve a pre-heating of the packing **86**, to avoid any formation of water droplets in the packing **86** during the start-up-phase.

FIG. **4** illustrates a gas purification system in the form of a carbon dioxide separation unit **240** in accordance with an alternative embodiment. Many of the features of carbon dioxide separation unit **240** are similar to the features of gas compression and purification unit **40**, and those similar features of FIG. **4** have been given the same reference numerals as those of FIG. **1**. The carbon dioxide separation unit **240** differs from the gas compression and purification unit **40** illustrated in FIG. **1** in that carbon dioxide is separated from other gases, such as air and nitrogen, by means of a cryogenic process. In a cryogenic process a carbon dioxide rich flue gas is compressed and cooled to such low temperatures that carbon dioxide is liquefied. Separation from other gases, boiling at lower temperatures than carbon dioxide, and sometimes referred to as "non-condensable gases" may then be achieved. Examples of non-condensable gases include nitrogen, oxygen and argon. Examples of cryogenic processes for carbon dioxide separation and recovery are disclosed in US 2008/0173584 and US 2010/0215566.

Returning to FIG. **4**, the carbon dioxide separation unit **240** comprises, as its main units, a gas compressor **240'**, illustrated with a compression stage **246**, an inter-cooling and mercury adsorption unit **254**, and a cryogenic separation unit **243**. The gas compressor **240'** may be rather similar to the compressor **40'** described hereinbefore with reference to FIG. **2**, and is driven by a motor **52**. Compressed gas is forwarded, via a duct **262**, to a first gas cooler **64** of the inter-cooling and mercury adsorption unit **254**. The first gas cooler **64** cools the gas to a first temperature, in a similar manner as described hereinbefore with reference to FIG. **3**, after which the cooled compressed gas is forwarded, via duct **80**, to mercury adsorber **66**. In mercury adsorber **66** mercury is adsorbed from the gas in a similar manner as described hereinbefore with reference to FIG. **3**. The cooled compressed gas is then forwarded, via duct **88**, to a second gas cooler **68**. The second gas cooler **68** cools the gas further to a second temperature, in a similar manner as described hereinbefore with reference to FIG. **3**. The further cooled compressed gas is then forwarded, via duct **92**, to a gas drier **70**. In gas drier **70** water vapour is adsorbed from the gas in a similar manner as described hereinbefore with reference to FIG. **3**. Optionally, the inter-cooling and mercury adsorption unit **254** may further comprise a gas-liquid separator, and/or a filter and/or a regeneration system of the types disclosed in FIG. **3**.

The gas leaves gas drier **70** via duct **272** and enters cryogenic separation unit **243**. In cryogenic separation unit **243** carbon dioxide is separated from non-condensable gases. Hence, a carbon dioxide rich stream, typically comprising liquefied carbon dioxide, leaves cryogenic separation unit **243** via duct **241** and may be transported away for carbon dioxide sequestration. A stream of non-condensable gases leaves cryogenic separation unit **243** via duct **245** and may be released to the atmosphere.

A cryogenic separation unit **243** may typically comprise a so-called cold box **247**. The cold box **247** may be a multi-pass heat exchanger, which may be made from aluminium, in which heating and cooling of various streams of the cryogenic separation unit **243** may be achieved. In accordance with one option, a cooling liquid circuit **290** is connected to the second gas cooler **68** for achieving the cooling of the gas to the second temperature. The cooling liquid circuit **290** could be connected to the cold box **247**, as indicated in FIG. **4**, to utilize the cooling capacity of the cold box **247** when cooling the coolant circulating in the cooling liquid circuit **290**.

Aluminium, which may be included as part of the structure of the cold box **247**, may react with mercury in an unwanted manner. By removing mercury from the carbon dioxide rich flue gas in the adsorber **66**, upstream of the cold box **247** of the cryogenic separation unit **243**, such problems are avoided, or at least minimized. Furthermore, in some cases it is also necessary to remove mercury from the carbon dioxide to meet the specification required for the carbon dioxide sequestration.

It will be appreciated that numerous variants of the embodiments described above are possible within the scope of the appended claims.

Hereinbefore it has been described how a gas purification system including a compressor **40'**, **240'**, a first gas cooler **64**, a mercury adsorber **66**, a second gas cooler **68**, and a gas drier **70**, may be integrated as part of a GPU **40**, as illustrated in FIGS. **2-3**, or may be combined with a cryogenic separation unit **243**, as illustrated in FIG. **4**. It will be appreciated that a gas purification system of this type, and a method of operating it, may also be integrated in other types of processes, where there is a need for removing mercury and water vapour from a carbon dioxide rich flue gas. Furthermore, the gas purification system of the above mentioned type may also be integrated in other parts of the GPU **40** and combined in other manners with the cryogenic separation unit **243** than those described hereinbefore.

To summarize, a gas purification system **40** for cleaning a carbon dioxide rich flue gas generated in a boiler combusting a fuel in the presence of a gas containing oxygen gas comprises:

a compressor **40'** for compressing the carbon dioxide rich flue gas,

a first gas cooler **64** for cooling the compressed carbon dioxide rich flue gas,

a mercury adsorber **66** arranged downstream of the first gas cooler **64** for removing at least a portion of a mercury content of the cooled compressed carbon dioxide rich flue gas,

a second gas cooler **68** arranged downstream of the mercury adsorber **66** for further cooling the compressed carbon dioxide rich flue gas, and

a gas drier **70** for removing at least a portion of a water content of the further cooled compressed carbon dioxide rich flue gas.

While the invention has been described with reference to a number of preferred embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiments disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims. Moreover, the use of the terms first, second, etc. do not denote any order or importance, but rather the terms first, second, etc. are used to distinguish one element from another.

What is claimed is:

1. A method of cleaning a carbon dioxide rich flue gas generated in a boiler combusting a fuel in the presence of a gas containing oxygen gas, the method comprising

compressing the carbon dioxide rich flue gas,

cooling the compressed carbon dioxide rich flue gas to a first temperature that is higher than a dew point temperature with respect to water vapour of the compressed carbon dioxide rich flue gas, forwarding the cooled compressed carbon dioxide rich flue gas through a mercury adsorber to remove at least a portion of a mercury content of the cooled compressed carbon dioxide rich flue gas,

further cooling the cooled compressed carbon dioxide rich flue gas to a second temperature, which is lower than the first temperature, and

forwarding the further cooled compressed carbon dioxide rich flue gas through a drier to remove at least a portion of a water content of the further cooled compressed carbon dioxide rich flue gas.

2. The method according to claim **1**, wherein the first temperature is 5° C. to 30° C. higher than the dew point temperature with respect to water vapour of the compressed carbon dioxide rich flue gas.

3. The method according to claim **1**, wherein the step of further cooling the compressed carbon dioxide rich flue gas to a second temperature, which is lower than the first temperature, comprises cooling to a second temperature that is lower than the dew point temperature with respect to water vapour of the compressed carbon dioxide rich flue gas.

4. The method according to claim **3**, wherein the second temperature is 0° C. to 40° C. higher than the carbon dioxide hydrate formation temperature of the compressed carbon dioxide rich flue gas.

5. The method according to claim **1**, wherein the step of compressing the carbon dioxide rich flue gas involves heating, by means of the compression of the gas, the compressed carbon dioxide rich flue gas to a temperature which is higher than the first temperature.

6. The method according to claim **5**, further comprising heating, by means of the compression of the gas, the compressed carbon dioxide rich flue gas to a temperature of 60° C. to 270° C.

7. The method of claim **1**, wherein the method is performed by a gas purification system that is configured to receive the carbon dioxide rich flue gas from the boiler for cleaning the carbon dioxide rich flue gas, the flue gas from the boiler being generated from the boiler combusting a fuel in the presence of a gas containing oxygen gas, the gas purification system comprising:

a compressor for performing the compressing of the carbon dioxide rich flue gas,

a first gas cooler arranged downstream, as seen in a direction of flow of the carbon dioxide rich flue gas, of the compressor for performing the cooling of the compressed carbon dioxide rich flue gas to the first temperature,

the mercury adsorber arranged downstream of the first gas cooler that removes the at least a portion of the mercury content of the cooled compressed carbon dioxide rich flue gas,

a second gas cooler arranged downstream of the mercury adsorber that performs further cooling of the compressed carbon dioxide rich flue gas, and

a gas drier arranged downstream of the second gas cooler that receives the forwarded further cooled compressed carbon dioxide rich flue gas and removes the at least a portion of the water content of the further cooled compressed carbon dioxide rich flue gas.

8. The method of claim **7**, wherein the gas purification system further comprises a control system comprising a sensor measuring the temperature of the cooled compressed carbon dioxide rich flue gas downstream of the first gas cooler, the control system further comprising a control device controlling the first gas cooler in view of the measured temperature.

9. The method of claim **7**, wherein the gas purification system further comprises a water trap arranged between the second gas cooler and the gas drier for collecting liquid water from the further cooled compressed carbon dioxide rich flue gas.

10. The method of claim **7**, wherein the gas purification system further comprises a heating system for forwarding a heated gas through the mercury adsorber prior to start-up of the gas purification system.

11. The method of claim **8**, wherein the second gas cooler further cools the compressed carbon dioxide rich flue gas to the second temperature.

12. The method of claim **7**, wherein the gas purification system further comprises:

a water trap arranged between the second gas cooler and the gas drier;

a control system comprising a sensor for measuring the temperature of the cooled compressed carbon dioxide rich flue gas downstream of the first gas cooler, the control system further comprising a control device controlling the first gas cooler in view of the measured temperature; and

a heating system for forwarding a heated gas through the mercury adsorber prior to start-up of the gas purification system; and the method further comprises:

collecting liquid water from the further cooled compressed carbon dioxide rich flue gas via the water trap;

measuring the temperature of the cooled compressed carbon dioxide rich flue gas downstream of the first gas cooler via the sensor;

controlling the first gas cooler in view of the measured temperature via the control device; and

forwarding the heated gas through the mercury adsorber prior to start-up of the gas purification system via the heating system.

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